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Inbreeding depression and heterotic response analysis for seed yield and its related attributes in yellow sarson (*Brassica rapa* var. yellow sarson)

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Abstract
Analysis of variances revealed that highly significant differences were found for all the characters. Highly significant differences were recorded among all the treatments for all the 15 characters except for number of primary branches per plant. Highly significant variability were found in the base materials as well as F_1 hybrids. Significant differences were also noted among parents vs. F_1s for all the characters. Significant differences were also noted among parents vs. F_2s for all the characters, except days to maturity, number of siliquae per plant and biological yield per plant. Significant differences among F_1s vs. F_2s for all the characters except for length of main raceme, leaf area index, number of primary branches per plant, harvest index and oil content. The estimate of $\hat{\sigma}^2 g$ were lower than $\hat{\sigma}^2 s$ for all the characters except number of secondary branches per plant and biological yield per plant, in both the generations. The cross combinations namely; B-09 x YST-151, YSKM-10-02 x YST-151, YSC-15 x YST-151, YSC-30 x YST-151 and YSC-84 x YST-151 were shown significant and positive heterosis over both better and economic parent and inbreeding depression for seed yield per plant.

Keywords: Inbreeding depression, heterotic response, seed yield, related attributes, yellow sarson (*Brassica rapa* var. yellow sarson)

1. Introduction
The olieferous *Brassica* species, commonly known as rapeseed-mustard, are one of the economically important agricultural commodities. Rapeseed-mustard comprising eight different species viz. Indian mustard, toria, yellow sarson, brown sarson, gobhi sarson, karan rai, black mustard and taramira, are being cultivated in fifty three countries spreading all over the globe. The genus *Brassica* has mainly a Mediterranean distribution, but it expands to Africa and Asia; including India. Rapeseed mustard group of crops play a vital role in human nutrition and oilseed economy of the country.

2. Materials & Methods
The experimental materials were comprised 25 lines namely, YSC-63, YSC-41, B-09, YSK-71, YSKM-11-02, YSC-76, YSKM-10-1, YSKM-11-1, YSC-75, YSKM-10-02, YSK-9-01, YSC-80, K-88, YSC-15, Type-42, YSC-18, YSK-03, YSC-21, YSC-92, YSC-45, YSC-30, YSC-95, YSC-40, YSC-46 and YSC-46 used as female and 4 testers namely, NRCYS-05-02, YSH-401, YST-151 and Pitambari (check) used as male of yellow sarson. The materials comprising of 29 parents + 100 F_1s + 100 F_2s were sown in Randomized Block Design with three replications during *Rabi* 2014-2015 at Oilseed Research Farm, Kalyanpur of C.S. Azad University of Agriculture & Technology, Kanpur-208002. All the Twenty five females were crossed with each of four males in line x tester mating deigns to produce sufficient amount of F_0 seeds of 100 crosses during the *Rabi* season 2011-12 to raise the F_1s. The F_1s were selfed in order to obtain F_2s seeds during the *Rabi* season 2012-13. The parents were also maintained through selfing in a Randomized Block Design with three replications at the Oilseed Research Farm, Kalyanpur of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur. Each treatment was planted in one row, of 3 m length and 45 cm apart, Plant to plant distance was maintained at 15 cm by thinning. All the recommended agronomic practices were adopted for raising a good crop. The observations were recorded on eight characters namely; number of siliquae per plant, number of seeds per siliqua, biological yield per plant (g), harvest index (%), 1000-seed weight (g), oil content (%), protein content (%) and seed yield

per plant. The analysis of variance for combining ability was carried out according to the method outlined by Kempthorne (1957). The oil content (% seed weight) and protein content (% de-oiled meal weight) was estimated by using Nuclear Magnetic Resonance (NMR) method.

3. Results & Discussion

The results of analysis of variance are presented in table-1. Analysis of variances revealed that highly significant differences were found for all the characters. Highly significant differences were recorded among all the treatments for all the 15 characters except for number of primary branches per plant. Highly significant variability were found in the base materials as well as F_1 hybrids. Similar findings were also observed by Sharma *et al.* (2003) [12] and Raj *et al.* (2005) [11], Arifullah *et al.* (2012) [1].

Significant differences were also noted among parents vs. F_1s for all the characters. Significant differences were also noted among parents vs. F_2s for all the characters, except days to maturity, number of siliquae per plant and biological yield per plant. Significant differences among F_1s vs. F_2s for all the characters except for length of main raceme, leaf area index, number of primary branches per plant, harvest index and oil content. The estimate of $\hat{\sigma}^2 g$ were lower than $\hat{\sigma}^2 s$ for all the characters except number of secondary branches per plant and biological yield per plant, in both the generations. These results are also similar to Sharma *et al.* (2004) [13], Singh *et al.* (2004) [20], Singh *et al.* (2006) [17, 21], Gupta *et al.* (2010) [5] and Singh *et al.* (2010) [25].

Heterosis was calculated in per cent over better as well as economic parents for all the seven characters. Estimate of inbreeding depression in F_2s over their respective F_1s were calculated in terms of percentage. The results of heterosis and inbreeding depression are shown in table-2. Negative and significant values of heterosis were considered desirable for days to 50% flowering, days to maturity and plant height. Out of 100 crosses top five best cross combinations namely; YSC-63 x YST-151, YSC-41 x Pitambari, B-09 x Pitambari, YSKM-10-1 x YST-151 and YSKM-11-1 x Pitambari were shown significant and negative heterosis over both better and economic parent and inbreeding depression for early flowering. The cross combinations namely; YSKM-11-02 x YST-151, YSC-76 x NRCYS-05-02, YSKM-11-02 x YST-151, YSC-18 x NRCYS-05-02 and YSC-21 x Pitambari were shown significant and negative heterosis over both better and economic parent and inbreeding depression for early maturity. The cross combinations namely; YSC-63 x NRCYS-05-02, YSKM-11-02 x YSH-401, YSC-80 x YSH-401, T-42 x NRCYS-05-02 and YSC-84 x YSH-401 were shown significant and negative heterosis over both better and economic parent and inbreeding depression for dwarf plant height. The cross combinations namely; YSC-41 x Pitambari, YSKM-11-02 x YSH-401, YSC-75 x NRCYS-05-02, YSC-15 x NRCYS-05-02 and YSC-15 x YSH-401 were shown significant and negative heterosis over both better and economic parent and inbreeding depression for length of main raceme. The cross combinations namely; YSC-63 x YSH-401, B-09 x Pitambari, YSC-75 x YSH-401, K-88 x NRCYS-05-02 and T-42 x YST-151 were shown significant and negative heterosis over both better and economic parent and inbreeding depression for leaf are index. The cross combinations namely; B-09 x NRCYS-05-02, YSKM-11-02 x YST-151, YSKM-11-1 x YST-151, YSK-9-02 x NRCYS-05-02 and YSC-46 x YST-151 were shown significant and negative heterosis over both better and economic parent and inbreeding depression for number of primary branches per plant and the cross combinations namely; YSKM-10-1 x NRCYS-05-02, K-88 x YSH-401, T-42 x NRCYS-05-02, YSC-92 x YST-151 and YSC-95 x NRCYS-05-02 were shown significant and negative heterosis over both better and economic parent and inbreeding depression for number of secondary branches per plant. These results are also similar to Sweta *et al.* (2005) [14], Tripathi *et al.* (2005) [27], Singh *et al.* (2006) [17, 21], Singh *et al.* (2008a.) [24], Singh *et al.* (2009) [15] and Verma *et al.* (2010) [4].

The top five best cross combinations namely; YSC-92 x NRCYS-05-02, YSC-45 x NRCYS-05-02, YSC-95 x NRCYS-05-02, YSC-40 x NRCYS-05-02 and YSC-84 x NRCYS-05-02 were shown positive and significant heterosis over both better and economic parent and high inbreeding depression for more number of siliquae per plant. The cross combinations namely; YSC-45 x NRCYS-05-02, YSC-95 x YSH-401, YSC-95 x YST-151, YSC-46 x Pitambari and YSC-84 x NRCYS-05-02 were shown positive and significant heterosis over both better and economic parent and high inbreeding depression for more number of seeds per siliqua. The cross combinations namely; YSC-45 x YSH-401, YSC-30 x Pitambari, YSC-95 x Pitambari, YSC-46 x YSH-401 and YSC-84 x YSH-401 were shown positive and significant heterosis over both better and economic parent and high inbreeding depression for biological yield per plant. The cross combinations namely; YSC-45 x YSH-401, YSC-30 x NRCYS-05-02, YSC-95 x Pitambari, YSC-40 x YST-151 and YSC-84 x YSH-401 were shown positive and significant heterosis over both better and economic parent and high inbreeding depression for harvest index. The cross combinations namely; T-42 x NRCYS-05-02, T-42 x YST-151, YSK-03 x YST-151, YSC-45 x NRCYS-05-02 and YSC-95 x YST-151 were shown positive and significant heterosis over both better and economic parent and high inbreeding depression for 1000-seed weight. The cross combinations namely; YSC-92 x YST-151, YSC-45 x YST-151, YSC-30 x YST-151, YSC-46 x YST-151 and YSC-84 x YST-151 were shown positive and significant heterosis over both better and economic parent for oil content. The cross combinations namely; YSC-95 x YST-151, YSC-40 x YSH-401, YSC-46 x YSH-401, YSC-84 x NRCYS-05-02 and YSC-84 x Pitambari were shown positive and significant heterosis over both better and economic parent and high inbreeding depression for protein content and the cross combinations namely; B-09 x YST-151, YSKM-05-02 x YST-151, YSC-15 x YST-151, YSC-30 x YST-151 and YCS-84 x YST-151 were shown positive and significant heterosis over both better and economic parent and high inbreeding depression for seed yield per plant. Similar results are also similar to Singh *et al.* (2003) [22], Singh *et al.* (2007) [16, 26], Singh *et al.* (2008b.) [23], Singh *et al.* (2009b.) [19], Chauhan *et al.* (2011) [2], Lal *et al.* (2013) [7], Prajapati *et al.* (2013) [9, 10] and Dutta *et al.* (2014) [3].

Table 1: ANOVA for 15 characters in line x tester analysis of yellow sarson (*Brassica campestris var. yellow sarson*): mean sum of squares (Parents + F_1s + F_2s).

Sources of variance	d.f.	Days to 50% flowering	Days to maturity	Plant height (cm)	Length of main raceme (cm)	Leaf area index (cm/m^2)	Number of primary branches per plant	Number of secondary branches per plant	Number of siliquae per plant
Replications	2	4.25	7.37**	67.22**	4.53	1.22**	1.80	19.57**	124.05**
Treatments	228	12.87**	13.79**	16.58**	9.94**	1.75**	1.16	3.81**	49.25**
Parents	28	22.10**	5.81**	9.37**	6.53**	1.70**	0.87	2.59**	43.96**
Lines	24	5.94**	2.64**	6.24**	5.83**	1.73**	0.91	1.43	27.97**
Testers	3	36.55**	21.55**	26.67**	11.41**	2.00**	0.75	0.75	30.97**
Lines x Testers	1	36.64**	34.51**	32.49**	8.69**	0.00	0.02	35.6**	466.69**
F_1s	99	7.18**	5.03**	3.75**	10.91**	1.98**	0.70	2.13**	15.54**
F_2s	99	3.44**	2.82**	5.23**	4.24**	1.54**	0.94	1.34	30.02**
Parents Vs F_1s	1	1196.00**	822.10**	2219.37**	64.36**	3.14**	55.41**	100.48**	2274.14**
Parents Vs F_2s	1	468.08**	1.56	562.66	66.96**	2.98**	7.33*	384.35**	1.33**
Parents Vs F_1s+F_2s	1	890.19**	211.83**	1413.08**	0.01**	3.45**	29.03**	247.25**	671.84**
F_1s Vs F_2s	1	372.88**	1991.08**	1216.78**	584.11	0.00	49.88	204.17**	4816.67**
Error	456	1.75	1.48	1.22	1.91	0.02	1.82	1.40	1.39

Table 1: Continue…………

Sources of variance	d.f.	Number of seeds per siliqua	Biological yield per plant (g)	Harvest index (%)	1000-seed weight (g)	Oil content (%)	Protein content (%)	Seed yield per plant (g)
Replications	2	7.24	14.29**	3.60	0.70**	9.94**	0.46**	0.33**
Treatments	228	15.81**	11.31**	5.59**	1.59**	3.15**	5.65**	2.02**
Parents	28	5.23**	5.15**	2.91**	0.77**	2.70**	4.10**	1.77**
Lines	24	5.13**	4.97*	2.44**	0.64**	2.96**	4.11**	1.70**
Testers	3	7.66**	8.00*	5.10**	0.11**	0.28**	2.55**	2.20**
Lines x Testers	1	0.20	0.73	7.42*	5.85**	3.55**	8.45*8	2.18**
F_1s	99	7.17**	15.69**	5.10**	0.52**	2.60**	3.17**	1.37**
F_2s	99	5.62**	1.63	5.85**	1.36**	2.66**	3.27**	1.55**
Parents Vs F_1s	1	2175.31**	211.32**	88.68**	50.67**	106.14**	498.75**	114.75**
Parents Vs F_2s	1	1122.28**	8.90*	102.98**	0.93**	109.66**	445.05**	99.04**
Parents Vs F_1s+F_2s	1	1808.97**	37.60**	107.81**	10.66**	121.56**	531.23**	120.27**
F_1s Vs F_2s	1	384.00**	682.67**	1.19	145.34**	0.06	3.40**	1.29**
Error	456	2.69	2.23	1.29	0.01	1.25	0.04	0.02

*, ** Significant at 5 and 1 per cent level, respectively.

Table 2: Heterosis over better and economic parent and inbreeding depression for fifteen characters in yellow sarson (*Brassica rapa* var. yellow sarson).

Characters	Cross combinations	Heterosis (%)		ID	SCA effects		GCA
		BP	EP		F_1	F_2	Effects
Days to 50% flowering	YSC-63 x YST-151	-17.44**	-6.40**	-0.62**	0.26**	-0.53**	H x H
	YSC-41 x Pitambari	-4.07**	-4.07**	0.60**	0.66**	0.48**	H x H
	B-09 x Pitambari	-7.56**	-7.56**	-5.66**	2.07**	0.69**	L x H
	YSKM-10-1 x YST-151	-20.00**	-9.30**	-3.84**	-0.51**	0.40**	H x H
	YSKM-11-1 x Pitambari	-9.88**	-9.88**	-6.45**	1.24**	-0.35**	H x L
Days to maturity	YSKM-11-02 x YST-151	-2.96**	-2.27**	-3.05**	-2.67**	0.36**	H x H
	YSC-76 x NRCYS-05-02	-2.44**	-2.27**	-3.33**	-1.48**	0.15**	H x H
	YSKM-11-1 x YST-151	-2.70**	-2.27**	-3.33**	0.50**	0.03**	L x H
	YSC-18 x NRCYS-05-02	-4.03**	-1.42**	-3.36**	-1.52**	-0.28**	H x H
	YSC-21 x Pitambari	-3.23**	-2.27**	-3.33**	-1.94**	0.22**	L x H
Plant height (cm)	YSC-63 x NRCYS-05-02	-4.78**	-3.04**	-5.00**	-2.74**	2.03**	H x L
	YSKM-11-02 x YSH-401	-7.29**	-3.04**	-4.45**	-1.72**	-0.10**	H x H
	YSC-80 x YSH-401	-7.29**	-3.04**	-5.56**	-1.93**	1.33**	L x H
	T-42 x NRCYS-05-02	-4.81**	-3.04**	-5.00**	-1.72**	-0.88**	H x H
	YSC-84 x YSH-401	-5.94**	-1.64**	-2.96**	-1.93**	1.34**	H x L
Length of main raceme (cm)	YSC-41 x Pitambari	-10.53**	-10.53**	-1.91**	3.12**	0.52**	H x H
	YSKM-11-02 x YSH-401	-5.56**	-10.53**	-0.65**	2.02**	0.89**	H x H
	YSC-75 x NRCYS-05-02	-7.27**	-10.53**	-3.92**	-1.00**	0.88**	L x H
	YSC-15 x NRCYS-05-02	-4.22**	-7.02**	3.77**	-1.34**	-1.87**	H x H
	YSC-15 x YSH-401	-7.83**	-10.53**	-3.26**	-2.63**	0.02**	H x L
Leaf area index (cm/m^2)	YSC-63 x YSH-401	66.1**	35.26**	32.40**	-0.01**	-0.56**	H x H
	B-09 x Pitambari	35.26**	35.26**	32.40**	0.92**	0.17**	L x H

	YSC-75 x YSH-401	77.36**	44.08**	54.98**	0.37**	-0.50**	H x H
	K-88 x NRCYS-05-02	156.98**	69.27**	24.40**	1.70**	-0.14**	H x L
	T-42 x YST-151	23.08**	69.27**	35.78**	1.09**	-0.11**	H x H
Number of primary branches per plant	B-09 x NRCYS-05-02	18.75**	26.67**	5.26**	0.18**	0.42**	H x H
	YSKM-11-02 x YST-151	50.00**	20.00**	16.66**	0.48**	0.26**	L x H
	YSKM-11-1 x YST-151	41.67**	13.33**	17.64**	-1.01**	0.48**	H x H
	YSK-9-01 x NRCYS-05-02	30.77**	13.33**	17.64**	-0.51**	0.97**	H x H
	YSC-46 x YST-151	50.00**	20.00**	16.66**	-1.35**	-0.11**	L x H
Number of Secondary branches per plant	YSKM-10-1 x NRCYS-05-02	13.89**	-5.13**	-2.43**	1.80**	0.27**	H x H
	K-88 x YSH-401	-7.89**	-10.26**	-8.57**	-0.66**	-0.36**	H x L
	T-42 x NRCYS-05-02	-8.33**	-15.38**	-22.27**	-0.11**	0.69**	H x H
	YSC-92 x YST-151	-13.89**	-5.13**	-2.43**	1.43**	0.65**	L x H
	YSC-95 x NRCYS-05-02	-5.56**	-2.56**	-10.52**	1.05**	0.44**	H x H
Number of siliquae per plant	YSC-92 x NRCYS-05-02	3.80**	11.58**	3.20**	0.10**	3.40**	H x L
	YSC-45 x NRCYS-05-02	3.09**	2.25**	3.91**	0.77**	0.77**	H x H
	YSC-95 x NRCYS-05-02	3.33**	2.03**	6.20**	0.32**	3.10**	L x H
	YSC-40 x NRCYS-05-02	3.56**	1.80**	2.98**	2.77**	1.23**	H x H
	YSC-84 x NRCYS-05-02	309**	2.25**	3.91**	0.77**	0.77**	H x L
Number of seeds per siliqua	YSC-45 x NRCYS-05-02	22.22**	26.92**	6.06**	1.88**	1.27**	H x H
	YSC-95 x YSH-401	27.85**	29.49**	10.89**	1.37**	0.73**	L x H
	YSC-95 x YST-151	25.32**	26.92**	6.06**	1.30**	1.27**	H x H
	YSC-46 x Pitambari	29.49**	29.49**	10.89**	2.37**	0.32**	H x L
	YSC-84 x NRCYS-05-02	23.75**	26.92**	6.06**	1.88**	1.27**	H x H
Biological yield per plant (g)	YSC-45 x YSH-401	6.52**	13.95**	10.20**	0.38**	0.22**	L x H
	YSC-30 x Pitambari	5.56**	10.47**	2.10**	1.97**	0.95**	H x H
	YSC-95 x Pitambari	4.26**	13.95**	10.20**	0.03**	0.07**	H x L
	YSC-46 x YSH-401	1.04**	10.47**	2.10**	0.12**	1.37**	H x H
	YSC-84 x YSH-401	6.52**	13.95**	10.20**	0.38**	0.22**	L x H
Harvest index (%)	YSC-45 x YSH-401	5.86**	9.41**	3.19**	1.93**	0.13**	H x H
	YSC-30 x NRCYS-05-02	0.95**	9.83**	8.33**	1.59**	0.96**	H x L
	YSC-95 x Pitambari	7.86**	9.41**	3.35**	0.79**	0.41**	H x H
	YSC-40 x YST-151	4.51**	9.83**	8.33**	1.71**	0.87**	L x H
	YSC-84 x YSH-401	8.34**	9.41**	3.19**	1.93**	0.13**	H x H
1000-Seed weight (g)	T-42 x NRCYS-05-02	13.36**	15.15**	13.61**	0.04**	0.20**	H x L
	T-42 x yst-151	7.97**	17.00**	13.02**	0.03**	0.28**	H x H
	Ysk-03 x YST-151	6.26**	15.15**	13.61**	0.16**	0.55**	L x H
	YSC-45 x NRCYS-05-02	17.64**	15.15**	13.61**	0.04**	0.20**	H x H
	YSC-95 x YST-151	6.26**	15.15**	13.61**	0.16**	0.55**	H x H
Oil content (%)	YSC-92 x YST-151	0.82**	0.31**	2.39**	1.00**	0.57**	L x H
	YSC-45 x YST-151	4.42**	2.94**	0.17**	0.59**	1.14**	H x H
	YSC-30 x YST-151	4.24**	2.76**	0.18**	0.32**	0.10**	H x H
	YSC-46 x YST-151	1.75**	0.31**	2.43**	1.00**	0.09**	L x H
	YSC-84 x YST-151	4.42**	2.94**	0.21**	0.59**	0.57**	H x H
Protein content (%)	YSC-95 x YST-151	9.36**	14.60**	0.37**	1.27**	1.39**	H x H
	YSC-40 x YSH-401	11.14**	15.24**	1.30**	1.60**	1.48**	H x H
	YSC-46 x YSH-401	9.66**	13.71**	0.66**	0.82**	1.10**	H x L
	YSC-84 x NRCYS-05-02	19.14**	14.60**	0.54**	0.94**	1.16**	H x H
	YSC-84 x Pitambari	15.24**	15.24**	1.09**	0.54**	0.55**	L x H
Seed yield per plant (g)	B-09 x YST-151	20.54**	3.35**	0.10**	0.35**	0.38**	H x H
	YSKM-10-02 x YST-151	10.08**	4.02**	9.53**	0.83**	0.87**	H x H
	YSC-15 x YST-151	18.91**	3.35**	6.96**	0.35**	0.40**	H x H
	YSC-30 x YST-151	7.67**	4.02**	6.86**	0.70**	0.87**	H x H
	YSC-84 x YST-151	7.27**	3.35**	7.45**	0.35**	0.63**	H x H

*, ** Significant at 5 and 1 per cent level, respectively

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